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SW-platform for R&D in Applications of Synchrophasor Measurements for Wide-Area Assessment, Control and Visualization in Real-Time

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SUMMARY

The Danish research project "Secure Operation of Sustainable Power Systems (SOSPO)" is currently being conducted in a collaboration by a group of partners from academia and industry. The focus of the project is on how to achieve secure operation of the power grid as large scale thermal power plants, supplied by fossil fuel, are phased out in favor of non-controllable renewable energy sources like wind and solar energy. In particular, the SOSPO project aims to develop real-time stability and security assessment methods as well as wide-area control methods to re-establish stable and secure operation when a critical operation has been identified.

An important part of the SOSPO project is the development of a SW-platform that enables testing and demonstrations of the various methods for wide-area assessment, control and visualization the project delivers. In order to test the methods under realistic conditions, the future system scenarios are represented in a real time grid simulator that is an integrated part of the platform. The SW-platform provides structured access to any model parameter as well as access to real-time phasor measurement unit (PMU) and remote terminal unit (RTU) snapshots. Having such structured access to relevant data greatly eases the implementation process of new methods.

The SW-platform is facilitated by PowerLabDK at the Technical University of Denmark, which is a new state-of-the-art experimental laboratory for technology development, testing, training and demonstration of technologies within electric power and energy. More specifically, the SW-platform exploits the Intelligent Control Lab facilities in PowerLabDK, which provides access to a powerful Real-Time Digital Simulator, a SCADA system, a full scale experimental power system control room with a video wall and an IBM Blade center for the implementation of the SW-platform and the wide-area methods developed in SOSPO.

This paper provides insights into the details of the SOSPO SW-platform including the technical infrastructure and the platform architecture

KEYWORDS

Real-Time Stability and Security Assessment, SW-Platform for Wide-Area Applications, Synchrophasors and Applications, Wide Area Monitoring and Control.

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INTRODUCTION

Modern societies are heavily dependent on a stable and secure supply of electric energy and will continue to be so in the future. Security assessment, which is traditionally carried out in a time-consuming offline process, is a key function to ensure a secure operation of electric power systems. The objective of the security assessment is to inspect a wide range of different contingencies to determine whether one or more of the contingencies would result in a stability problem. Prior to the deregulation of electric power systems, the most critical contingencies were known by the system operators due to their experience of operating the system in conditions where the hourly, daily, weekly and seasonal variations in consumption were known. The high predictability of the operating conditions hours and even days ahead resulted in that the offline approaches were well suited to ensure secure system operation.

The deregulation of power systems together with the increasing share of power production based on renewable energy sources (e.g., wind and solar energy) have increased the system operation complexity where the consumption and production is less predictable and fluctuates more than before. When the power production becomes subject to the prevailing weather conditions, the planning for stable and secure operation can no longer be made a few hours ahead. The fluctuating power production introduces a need for short-horizon supervision and fast coordination of control actions that ensure the system security in real-time.

The introduction of phasor measurement technology [1] together with advances in communications and computational facilities has stimulated the research and development of real-time applications for wide-area control, protection and monitoring. The Danish research project “Secure Operation of Sustainable Power Systems” (SOSPO) [2] focusses on research and development of methods that enable security assessment to be carried out in real-time and methods for wide-area control that automatically remedy a critical operating condition when a stability or a security problem has been identified. An important outcome of the SOSPO project is the development of a SW-platform, where the developed approaches for wide-area assessment and control are to be implemented and tested. The SW-platform is interfaced with a Real-Time Digital Simulator (RTDS®), which enables performance testing of the developed methods in a real-time closed loop environment using realistic future electric power system scenarios. The objective of this paper is to describe the details of the SOSPO SW-platform, starting with a general overview of the SOSPO project.

OVERVIEW OF THE DANISH SOSPO RESEARCH PROJECT

The Danish research project SOSPO launched in early 2012 and contributes to the solution of a critical and underestimated problem that must be addressed in order to realize a future scenario of sustainable electric power systems. In the future scenario, a large share of the power generation is based on renewable energy sources that are mainly non-controllable (e.g. wind and solar energy) resulting in the power production becoming subject to the prevailing weather conditions. To assure stable and secure operation of such systems, the project focusses on the development of methods for real-time monitoring of security margins, the closeness to stability boundaries and as well, methods for determining necessary coordinated control actions to regain secure operating conditions. To set appropriate scope for the SOSPO research, the following assumptions are made about the future power system characteristics:

- A very high share of the power production capability is based on fluctuating and non-controllable sustainable energy sources such as wind and solar energy;
- A measurement dataset that provides full observability of the grid can be obtained in real-time by the use of PMU measurements;
- Load is partly controllable and represented as aggregations at lowest voltage levels of the bulk power system as e.g. distribution cell or virtual power plant (VPP). The controllable load may be used as a resource for remedial control actions.

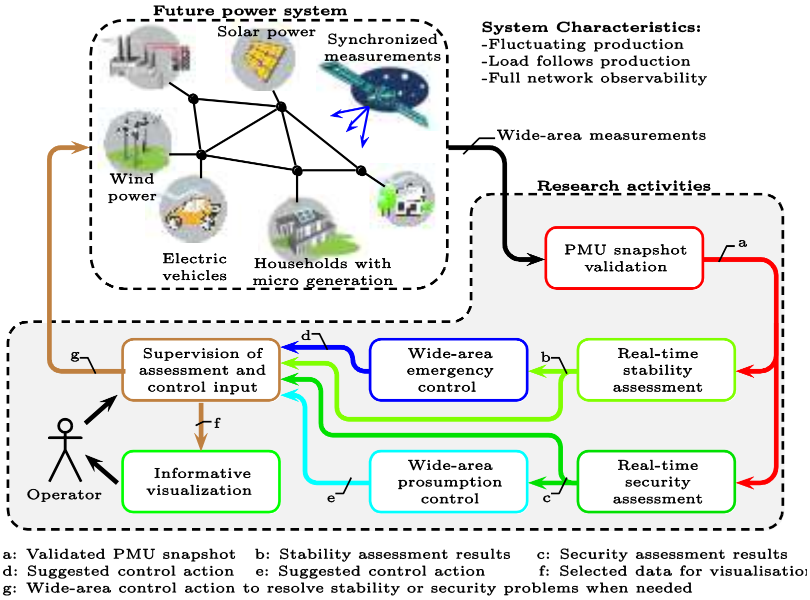

Fig 1: Conceptual overview illustrating main research activities in the SOSPO project and how the research results contribute to an overall approach for ensuring secure operation of future power systems.

Fig.1 provides a conceptual overview of the main research activities in the project. The figure depicts a future power system having characteristics as specified above and a platform consisting of several functional modules, where each module represents results from the major research activities in the SOSPO project. The following describes the functionality of the platform and thereby as well the main research activities in the SOSPO project.

The platform receives synchronized PMU snapshots from the power system in real time. Before the measurement can be used for assessment and control, it needs to be ensured that the snapshot represents an actual operating condition. The first module serves as a snapshot validation, where methods capable of identifying faulty data in PMU snapshots and replacing the faults with realistic estimates are to be developed and implemented. The module output (a) is a validated PMU snapshot, used as input to modules for assessing the observed operating point and it's distance to the security and stability boundaries in real-time.

The information concerning the system's critical operational boundaries (b and c) is used by two wide-area control modules. The first module, a wide-area prosumption control module, copes with security problems by altering the system prosumption patterns, where the term prosumption refers to aggregation of controllable loads and distributed generation resources. The second control module determines control actions that avoid impending instability, when the stability assessment module has identified an emergency situation. The output from the two control modules (d and e) are suggested control actions to remedy the identified problem.

The stability and security assessment results (b and c) and the suggested Wide Area Control (WAC actions (d and e) serve as inputs to a supervision module that gathers the information and determines what should be presented to the system operator (f) and carries out the corrective actions automatically (g) during critical conditions. The visualization module supports the operator's situational awareness by informative visualization of relevant stability and security information, potential countermeasures and the states of alert, such that the operator can intervene if needed.

The solutions to be developed in the SOSPO project exploit wide-area measurements to assess the system conditions and apply intelligent control, when needed, to a part of the system load with intrinsic energy storage capacity. To support and demonstrate SOSPO R&D, all developed methods will be gathered into a coherent operational SW-platform that enables realistic testing of how well the different methods would work in real operation.

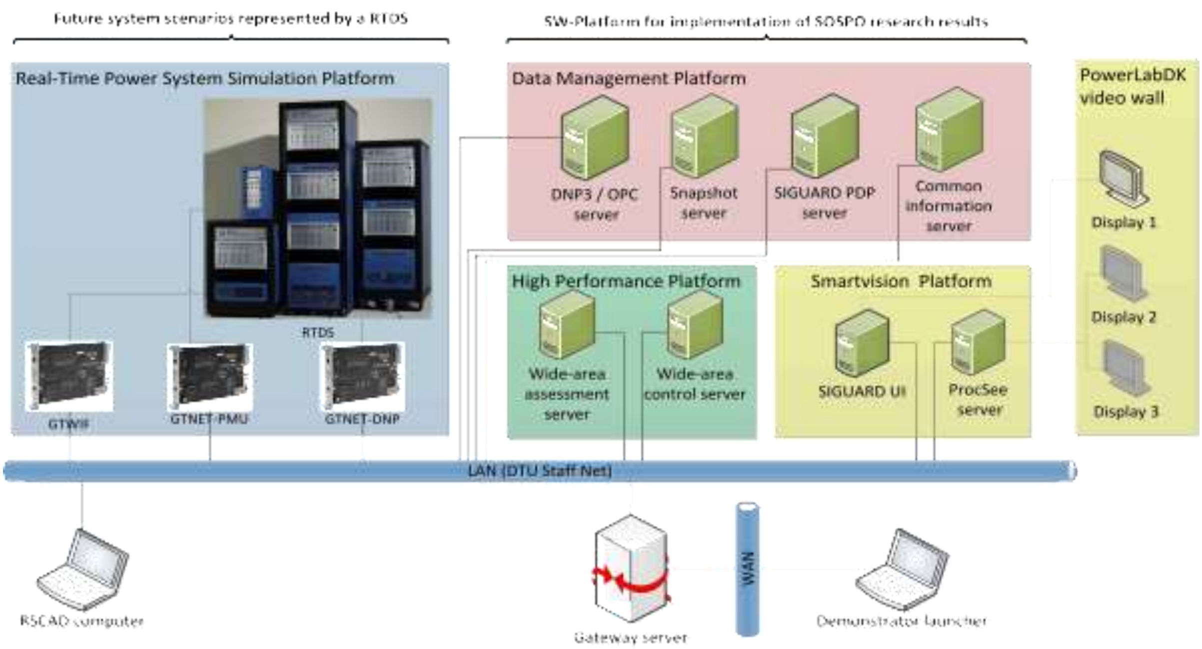

Figure 2: Technical infrastructure used for large-scale testing and demonstration of SOSPO deliverables at PowerLabDK

SW-platform to support R&D of wide-area assessment, visualization and control

Fig. 2 provides an overview of the technical infrastructure used for the establishment of the SW-platform where the methods developed in the SOSPO project, for assessment, control and visualization, are to be implemented and fig. 3 shows the platform architecture.

The SW-platform is facilitated by PowerLabDK [3], a new state-of-the-art laboratory for technology development, testing, training and demonstration of technologies within electric power and energy. The facilities range from flexible fundamental research and test laboratories to large-scale experimental facilities and a complete full-scale distribution system (the island of Bornholm with 27,000 customers and 33% wind power penetration) that serves as a platform for full-scale and real-life experiments. The facilities are linked together with communication systems and SCADA-solutions across four remote locations.

The SW-platform exploits a number of important PowerLabDK facilities such as a RTDS Simulator, a full scale ABB Network Manager SCADA system, a full-scale experimental power system control room with a video wall and an IBM Blade center for the implementation of methods originating from the SOSPO project. Fig. 2 illustrates the PowerLabDK facilities exploited for the construction of the SW-platform.

Fig. 2 and 3 show that the overall platform is divided into four main parts; i) a *RTDS Simulator Platform* that is used to represent the power systems of the future with closed loop interfaces to other platforms, ii) a *Data Management Platform* that stores system model information, and provides access to real-time PMU and RTU measurements for other parts of the platform; iii) a *High-Performance Platform* for implementation of fast algorithms for stability and security assessment, and wide area control; iv) a *Smartvision Platform* and video wall are used for implementation of methods for informative visualization. Description of each of the four main parts of the platform is provided in the following.

The Real-Time Power System Simulation Platform: Fig. 1 shows that the SOSPO objective is to develop a range of different methods for observing the operating conditions in future systems and interface with control actions in a closed loop when necessary. To test this closed loop functionality, it is necessary to have an appropriate representation of the future power system.

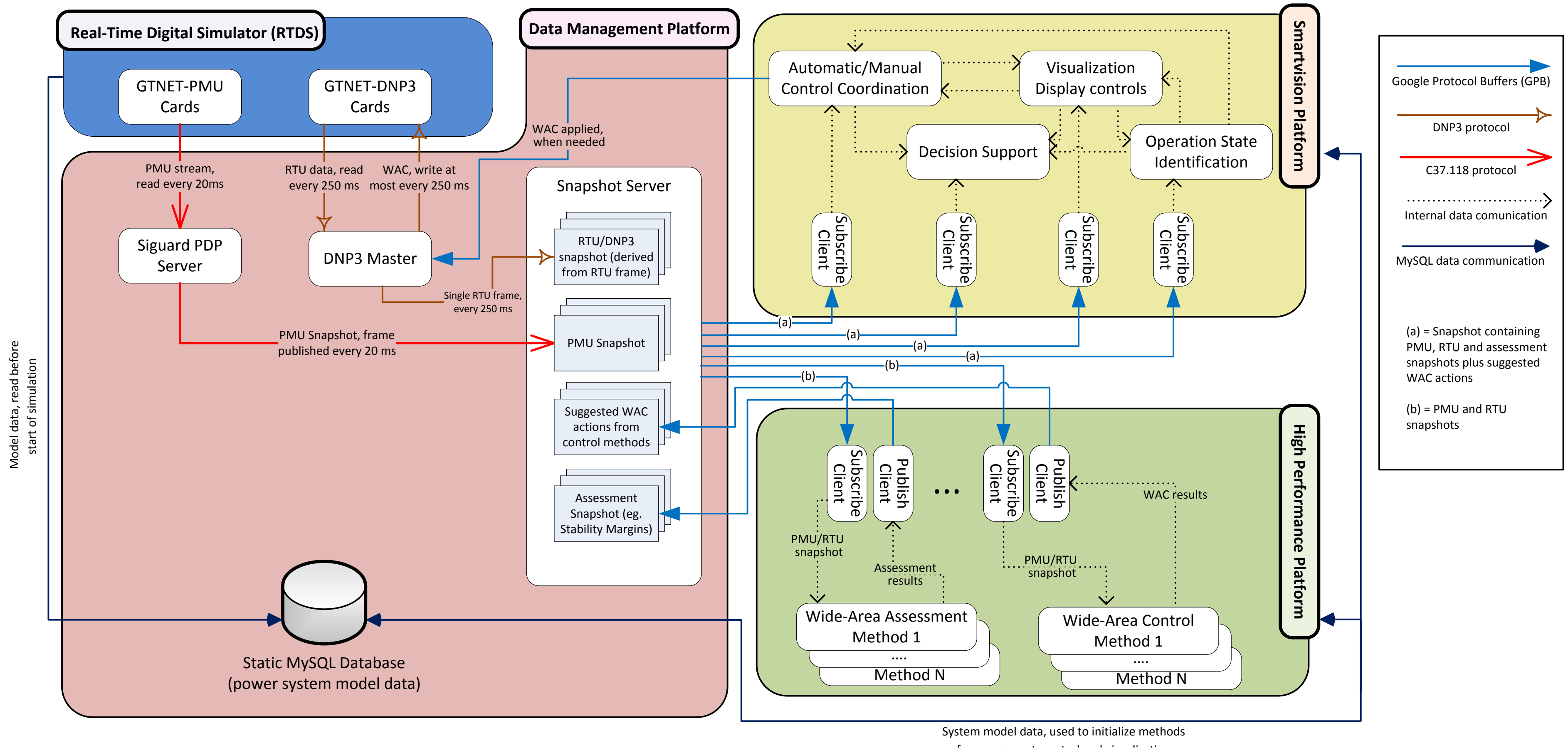

Fig. 3. The SW-platform architecture. The left-hand side (RTDS Simulator and Data Management Platform) may be used as a generic platform for supporting R&D of applications of wide-area data in real-time, since it provides structured access to model details, measurements and various setpoints. The left-hand side can be of great value for many different kinds of research projects (e.g. adaptive relays, control of multi-terminal DC and etc.) where real-life performance of the developed solutions is to be demonstrated. The right-hand side of the platform is project-specific, where in this case R&D results of the SOSPO projected are implemented.

For this purpose, the RTDS Simulator is an essential component for the overall functionality of the SW-platform. The RTDS simulates realistic operating conditions in real-time, with closed-loop SW interfaces such as PMU and DNP. The RTDS PMU interface enables streaming of wide-area measurements, as if they were coming from a real system. The RTDS DNP interface enables that the simulated system reacts to any control action based on the received measurements while the simulation is running.

The RTDS Giga-Transceiver Network Communication DNP (GTNET-DNP) card receives information about the system model being used and obtains real-time measurements of various system parameters that are provided by RTU in practical power systems. The GTNET-DNP cards are also used for applying wide-area control (WAC) actions to the running simulation. The RTDS GTNET-PMU cards provides snapshots of the system conditions according to the IEEE C37.118-1a™-2014 and IEEE C37.118.2™-2011 standards.

With a RTDS Simulator that has capability to produce PMU data according to the latest standard and having a well-known interface such as DNP, a SW-in-the-loop application of the RTDS will be demonstrated within the SOSPO project.

The Data Management Platform: The information communicated through the RTDS GTNET cards is sent to an IBM Blade Center, where four distinct servers are installed as illustrated in fig. 2. The SIGUARD PDP Server is used to concentrate all the PMU data received from the GTNET-PMU cards, align the data by time tags to generate PMU snapshots of the system conditions. SIGUARD PDP is commercialized by SIEMENS (a partner in the SOSPO project) who has the goal of monitoring the power transmission network using PMU data. The SIGUARD PDP Server allows the use of different protocols like the IEEE C37.118 [4], the Inter-Control Center Protocol (ICCP) and the OPC (OLE for Process Control). The SW-platform exploits the C37.118 protocol as seen in fig. 3, which ensures snapshot repetition time of 20ms.

The DNP3 server is used for bi-directional communication from the *Data Management Platform* to the RTDS Simulator. The platform receives RTU measurements through the DNP3 protocol from the RTDS and communicates wide-area control actions (in the form of set point adjustments) to the RTDS. Exploiting the DNP3 protocol, the fastest read and write repetition is 250 ms.

The Common Information Server hosts a static database that contains details of the power system model used in the RTDS simulation. The model details can be accessed by any of the other sub-platforms as needed. The static database is implemented in MySQL 5.5. In the future, this database can be extended to include other information such as contracts with prosumers, the prosumer characteristics and forecasts of generation etc.

The Snapshot Server is a central element in the SW-platform and it is responsible for the aggregation of measurement snapshots and assessment results and making it accessible to any other part of the platform that utilizes this information. All other servers or clients can access the Snapshot Server using the Google Protocol Buffers (GPB), which is a method of serializing structured binary data. The GPB uses an interface description language to describe the structure of the data and a program that generates source code from the description in various programming languages for generating or parsing a stream of bytes that represents the structured data. The SW-platform currently allows C/C++, Java, Python and Matlab clients.

The *Data Management Platform* together with the *RTDS Simulator Platform* provide structured access to any information needed to test or demonstrate new applications of wide-area measurements and therefore may be of great value for many future research projects.

The High Performance Platform: One of the main objectives of the SOSPO research project is to develop methods for assessment and determination of remedial control actions in real-time. The PMU technology ensures that observations of the system state may be received in real-time with high repetition rate (every 20 or 16.6ms). The major challenge in developing real-time assessment and control methods is related to algorithm development and the computational performance of implemented algorithms. Thus in the SOSPO project, a high focus is on the algorithms optimization, the use of parallelization techniques and on the use of adequate hardware.

The High Performance Platform provides the framework for efficient algorithm implementation. The platform is implemented in Linux and the assessment algorithms are developed in C/C++ which uses many state-of-the-art libraries and packages for numerical computations [6]–[8]. Fig. 3 illustrates that each implemented assessment or control method produces a snapshot of assessment results or suggested control actions, which are published at the Snapshot Server through the GPB. For each method, one pair of snapshot and subscribe clients are used to receive and send snapshots from and to the Snapshot Server. This structure enables that the methods can be executed individually.

At the current stage, several methods that have been developed under the SOSPO project will be implemented in the SW-platform. These assessment and control methods are: i) a patented method for assessment of aperiodic small-signal rotor angle (ASSRA) stability [9], [10], which is based on algebraically derived expressions for stability boundaries[11] that supports assessment times in milliseconds [12] and informative visualization [13]; ii) patented method for fast computations of N-1 post-contingency steady state snapshots used to static security assessment [14]; iii) method for fast security assessment of transient voltage dips following severe disturbances [15]; iv) patented method for automatically determining generation set point adjustments to avoid ASSRA instability [16]; and v) method for automatically varying system prosumption patterns to avoid ASSRA instability [17], [18].

The Smartvision Platform: All the information obtained from measurements and the various methods for assessment and control needs to be analysed to identify critical operating conditions and visualized in an informative manner to provide decision support to system operators. On the Smartvision Platform, new methods for identifying the criticality of the operating state (normal, alert or emergency), for coordination of automatic and manual control and for useful information to the operators in a large displays will be implemented.

In fig. 3, the *Operation State identification* module contains algorithms that use results from the assessment methods to determine the criticality of the operation. The main goal is the fast identification of alert and emergency situations to determine whether remedial actions should automatically be carried out or whether the operator should be “in-the-loop” when the actions are carried out. The operation state identification is implemented in a rule based system using the Jess 7.1.0 programming language. The *Control Coordination* sends the control action to the RTDS Simulator through the DNP3 master.

The access to measurement, assessment and control snapshots on the Snapshot Server is provided through subscribe clients implemented in Java, which is the chosen programing language for the Smartvision Platform. For the visualization of the relevant information received from the Snapshot Server, the PowerLabDK’s video wall is used where the visualization approaches are implemented in the ProcSee software tool that is intended for development and display of the dynamic graphical user interfaces.

Demonstrator Launcher: The distributed nature of the SW-platform requires a single executable that allows the coordination of the necessary processes. The demonstrator launcher is a GUI designed for Linux and Windows platforms. It can start and stop simulation scenarios on the RTDS used for demonstration of the SOSPO methods implemented on the SW-platform.

CONCLUSION

This paper describes the details of a SW-platform developed for supporting research and development of real-time applications for wide-area assessment, control and visualization. By using a RTDS simulator, an arbitrary system can be studied where the SW-platform ensures a structured access to any model detail and streams of PMU and RTU snapshots in real-time.

The platform was developed to support research in the Danish SOSPO project, where focus is on development of methods for real-time stability and security assessment and methods for determining a set of WAC actions to remedy a critical operating condition. The platform may also be of great value in many other future research projects, where the objective is to exploit wide-area measurements for a system with arbitrary characteristics for a given purpose.

A potentially added value of the platform is related to training power system operators in how to cope with the future systems. To do so, a representation of a future system scenario with a high penetration of fluctuating renewable energy sources can be simulated in the RTDS and the operators could be trained in ensuring secure and stable operation of such systems during critical conditions by putting the solutions that ongoing and future research may deliver into practice.

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